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Parametric Performance Study of Tunnel Boring Machine (TBM) In the Titiwangsa Main Range Granite, Malaysia

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Abstract

This paper presents a case study on the performances of Tunnel Boring Machine (TBM) opted for the construction of the Interstate Raw Water Transfer (ISRWT) project currently constructed in Selangor-Pahang, Malaysia. The performance of TBM is affected by various properties of rock mass such as the strength of rock, the occurrence of fault zone, the joint orientation and the existence of a water bearing zone. In this project, the 44 km Interstate Raw Water Transfer tunnel is designed to cross solid rock along the alignment with the overburden ranges from just several meters at each portal to more than one thousands meters at the centre of the tunnel. Geology of the alignment comprises of metasedimentary rock at the northern end and granitic rock to the rest of the tunnel. The method used for this study and the evidence are discussed.

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Keyword: Tunnel Boring Machine (TBM), tunnelling, Titiwangsa Main Range Granite, water, joint, wear rate.

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1. Introduction

The growing concern of water shortage in the western states of Peninsular Malaysia includes Selangor, Kuala Lumpur and Putrajaya due to the expanding population and booming economy has initiated the idea of channeling water from Pahang to Kuala Lumpur via a tunnel. In this project, the Malaysia Government proposed the construction of the 44.6 km long Pahang Selangir Raw Water Transfer (ISRWT) tunnel that will transfer water from Semantan River to the heart of Kuala Lumpur. The tunnel will channel raw water from the Semantan River, near to Kampung Jambu Rias, at the northeast part of Kuala Lumpur through the Main Range to the Hulu Langat, Selangor near to Kuala Lumpur where the water will be treated before piped to the consumers. The Interstate Raw Water Transfer tunnel is designed, for the first time to cross solid rock of the Titiwangsa Main Range granite along the alignment with the overburden ranges from just several meters at each portal to more than one thousand meters at the centre of the tunnel. Geology along the alignment comprises of metasedimentary rock at the northern end and granitic rock to rest of the tunnel. Generally, the Titiwangsa Main Range Granite is the predominant geological formation at tunnel level throughout the route with some part of the Karak Formation, Semantan Formation and Jelebu Schist Formation, thus highly variable of tunnel face condition was expected to encounter throughout the 44 km construction of the tunnel. The tunnel is designed to be

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constructed in two different methods of construction with 70% of the alignment will be constructed using TBM whilst the final 30% of the line will be using the New Austrian Tunneling Method (NATM). The purpose of this study is to investigate the effect of rock mass condition on TBM performance.

2. Geology of the area

The geology along the tunnel route is predominantly the Main Range granite batholith with a lesser extent of meta-sedimentary rocks of the Karak Formation (Fig. 1). The depth of the tunnel ranges from 25 m to 1315 m below the ground surface as it passes through the Main Range. These zones intruded into the Paleozoic clastic and calcareous metasediments (Pitfield *et al*., 1990). The granitic rocks along the proposed tunnel route can be divided into 3 types: first is the Kuala Lumpur Granite; second is the Genting Sempah Microgranite and third is the Bukit Tinggi Granite. Geochronological studies indicate that the granitic rocks were emplaced during Late Triassic. The Kongkoi Fault separates the Kuala Lumpur Granite from the Genting Sempah Microgranite and has a metasedimentary screen on its west flank. Similarly, the Genting Sempah Microgranite is separated from the Bukit Tinggi Granite by the Bukit Tinggi Fault. There is a systematic relationship between the joints, flow structures, geometry of the granite plutons, dykes and faults.

3. Research methodology

The effect of rock mass quality on the performance of TBM was studied from tunnel distance (TD) 2000 to 4000 m. Studies were carried out based on the analysis of three different data collected at the tunnel site, first is the daily tunnel mapping record, second is the TBM performance data and third is the lab test results of UCS on rock samples cored for every 50 m of the tunnel. The daily mapping of the tunnel rock mass records the strength of intact rock, joints properties and groundwater condition. The evaluation on the performance of TBM was made based on few parameters such as boring energy, rate of penetration (ROP) and rate per minute (RPM).

4. The effect of rock formations on TBM performance

The selection of open type TBM was made considering the geological condition of the proposed alignment such the hard rock of Titiwangsa Main Range Granite. The granitic rock had experienced series of faulting and folding (Shu, 1969 & Stauffer, 1968). Few difficult excavations by the TBM were envisaged due to the existence of fault zones, high overburden and potential risk of crossing water bearing zones. In Karak site, TBM-1 is most unexpectedly encountered few locations of high water bearing zones (Fig. 2). One of the locations is at Ch. 9001 (TD 2180m) in which approximately 10 ton/min (average of 4.1 ton/min) of sudden inrush warm water was recorded (Fig. 3). At this exact location, TBM recorded 46.50 N/mm^2 of boring energy, 7.10 rev/min of RPM and 0.80 m/h of ROP. It was unexpected condition as the three parameters of TBM showed constant rates of reading until it's suddenly hit the water pocket zone. Another encountered was at Ch. 9939 (TD3118) to Ch. 10019 (TD3198), where approximately 10.7 ton/min of warm water at temperature 33°C inrush into the tunnel from highly fractured, smooth planar, closely to medium spaced joints, oriented at N180°/70°-80°. The rock mass conditions were generally good, classified as rock class CII to D, based on Japanese Highway system of rock mass classification.

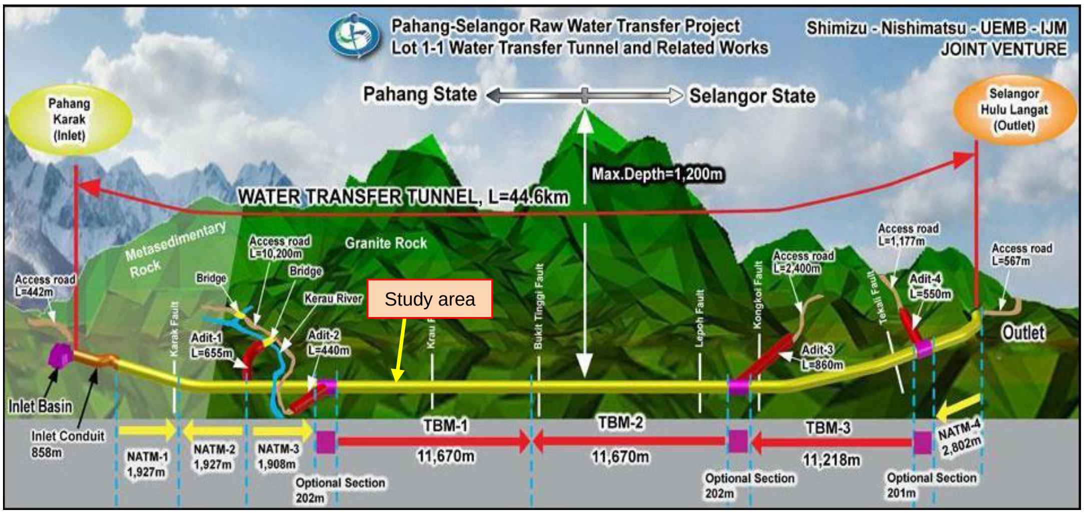

Figure 1: The geological map of the study area

Whilst in TBM-2, high water ingress occurred and had caused the face collapse too. The first major water ingress occurred at Ch.27962 (TD2200) ~ Ch.27402 (TD2760), where approximately 5.4 ton/min of water gushing into the tunnel system (Fig. 3a). The second incident occurred at Ch.30066 (TD 95.2m), water ingress was recorded at 5 ton/min (average 1.8 ton/min), believed due to the occurrences of highly fractured zone of Kongkoi Fault, positioned at Ch.31200 (Fig 3b). Tunnel face collapses were encountered at few points of TBM-2 with major collapse occurred at Ch. 28591 (TD 1571m) and this is believed due to the existence of Lepoh Fault (Ch.28600). But, the collapse started to occur after the TBM passed the zone with the collapsing of loose rocks onto the TBM and created a chimney shape of hole with 50 m high and 5 m wide above the TBM.

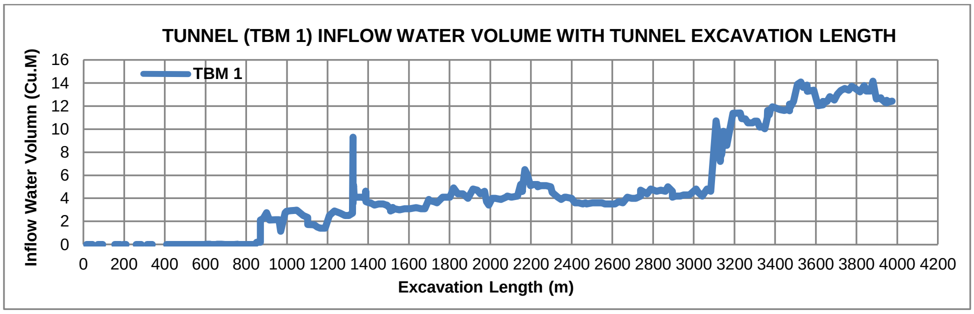

Figure 2: Water inflow of TBM-1, recorded between tunnel distances (TD 2000 – 4200).

Figure 3: (a) Ingress Water at TBM back up trailer (Max. 1.3m high at TBM); (b) Ingress water at right crown (3.5 ton/min); (c) Ingress water during carry out probe drill at TD 2768; (d) Ingress water from TBM hopper

There are many models and equations developed in estimating the performance of TBM ahead of the boring. In many of the models, UCS value of rock is the common parameter used, even though the usage of UCS solely may not provide accurate results (Cigla *et. al.,* 2001 & Yagiz, 2006). In this project, UCS values were recorded for every 50 m of the tunnel in addition to the daily reading of Schimdt Hammer rebound value, Fig. 4a. The two tests showed a satisfactory correlation as the rebound hardness values decreased with the decreasing value of UCS, particularly at TD800 and TD 2100 – 2500. A similar pattern is also seen in boring energy and daily progress of TBM, Fig. 4b. There were slightly dropped of boring energy and daily progress of TBM at TD800 and TD2100.

As shown in Fig. 4 (a & b), excavation at TD 2100-2250 (Joint orientation = N180°E /80°) showed high grade rock that required high type of support system because the presence of sheared zone of fresh rock. Boring energy is low since there was favourable oriented of fractures, whereas water ingress was very high at more than 300 litre/min which weaken the rock into smaller pieces and caused the excavation progress per day is high.

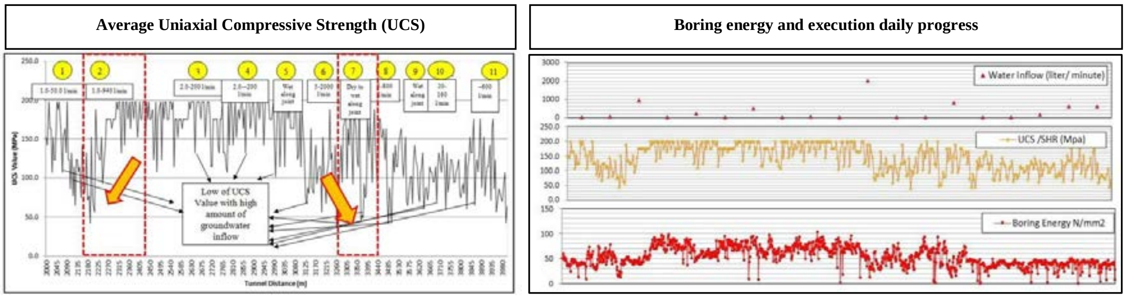

Figure 4: (a) Recorded values of UCS; (b) Boring energy and execution daily progress of TBM-1 between TD 2000 until 4000 m

5. UCS vs. TBM performance

Two (2) sets of data were executed, namely ‘UCS/SHR value’ and ‘UCS rock core’. Data sets of ‘UCS/SHR value’ is derived from the Schmidt Hammer Rebound (SHR) test while ‘UCS rock core’ is the result obtained from the UCS test that were carried out by taking rock core of every 10 m cut-off. However, rock cores for the UCS test were taken at fresh rock area or non-discontinuities area. In this case, the Schmidt Hammer Rebound (SHR) test is a very convenient and effective alternative to derive the UCS value, since SHR test promptly using on-site testing equipment.

Provided the UCS estimation from an axial SHR value were determined, the SHR test can lead more convenient and cheaper (Kohno and Maeda, 2010). Therefore, data set of ‘UCS/SHR value’ is selected compared to data set ‘rock core UCS’ since this data set is more dependable and accurate. Three **(**3) blocks from the study area (taken at TD 2150, TD 3250 and TD 3650 where the high groundwater inflow was recorded) were tested for UCS (Dry & Wet). Table 1 displays the results of Uniaxial Strength Test (UCS) for dry and wet specimen respectively. The relationship shows that sample C has the highest compressional value, followed by sample A and B. Table 1 verifies that the strength of rock decreased or becoming less, more than 50% from its dry value when it is wet or drained.

Table 1: UCS result for dry and wet specimens

Dry / Wet	Specimens	UCS (MPa)	Young's Modulus , E (GPa)	E’ (GPa)	ν
Dry	**AD1**	176.048	56.875	375.326	0.151
	AD2	160.285	59.888	480.65	0.124
	AD3	143.119	56.888	480.65	0.118
Wet	**AW8**	69.761	31.674	449.675	0.07
Dry	**BD1**	132.129	56.525	320.14	0.176
Wet	**BW5**	52.354	62.272	325.602	0.191
Dry	**CD1**	246.981	82.106	447.441	0.183
	CD3	241.543	85.402	437.977	0.194
Wet	**CW3**	123.566	52.431	502.677	0.104

Although the effect of water on the strength properties of rocks has been investigated, documented and explained relatively well by field data and correlation graph above, sometimes, data are not available and little is known about the deformability of rocks under wet conditions. Based on the uniaxial test results obtained for sandstones from the Arkagalinsk and Sangar coal fields in Yakutia (Russia), Burshtein (1969) showed that an increase in moisture content resulted in a significant decrease in the Young's Modulus of deformation of these rocks, both under compressive and tensile conditions (this effect manifested itself stronger in the case of rocks with a lower water capacity and was weaker in the case of rocks with a higher water capacity).

Table 2 showed that the existence of water reduced the rockmass strength especially at highly jointed rock. The table presented the relationship between the 11 points of jointed (high groundwater inflow occurred) with the UCS values. Thereby explains that a rock property such as rock strength (compressional value) is decreased by the existence of water. As according to the Nilsen and Thideman (1993) and Karlsrud (2002), most of the groundwater inflow occurred at any part of the tunnel mainly confined at joints or in fractures, faults and weathered zones.

Table 2: Relationship between jointed rock with high groundwater inflows and UCS value

No.	Tunnel Distance (m)	Joint Orientation (Dominant)	Point with low RQD (m)	Rock Quality Designation (RQD)	UCS/SHR (MPa)	Rock Core UCS (MPa)	UCS Value data (MPa)	Rate of Water Inflow (litre/minute)
1.	2030-2100	**N250E/80** **N300E/90**	This area is negligible since there is no relation between low value of UCS with high amount of groundwater inflow					1.0-50.0
2.	2100-2320	**N170E/85** **N180E/90**	2190 2210	40-70	56.50	56.50	176.048 (Dry) 160.285 (Dry) 143.119 (Dry) 69.761 (Wet)	1.0-940
3.	2660-2833	**N180E/90** **N290E/85**	This area is negligible since there is no relation between low value of UCS with high amount of groundwater inflow					2-~200
4.	2850-2990	**N190E/80** **N240E/90** **N270E/70**						Wet along joint - 500
5.	3000-3119	**N250E/80** **N160E/80**						Dry-50
6.	3119-3278	**N180E/80** **(Open Joint)**	3195	30-70	56.50	152.00	132.129 (Dry) 52.354 (Wet)	5-2000
7.	3298-3306	**N260E/60** **N170E/85**	3260	70-80	37.00	162.00	NA	Dry to wet along joint
8.	3356-3582	**N160E/80** **N180E/60** **(Open Joint)**	3365 3375 3485	50-70	45.70	107.40		5-800
9.	3590-3638.23	**N180E/70** **N290E/70**	-	40-70	49.10	180.10		Wet along joint
10.	3648.23-3838.23	**N250E/70** **N180E/70** **(Open Joint)**	-	60-70	42.60	103.90 149.00	246.981 (Dry) 241.543 (Dry) 123.566 (Wet)	20-160
11.	3868 - 4002	**N227E/60**	3995	70	42.6	NA	NA	600

Legend

N180E/70 ~45° from the tunnel drive direction (parallel to lineament line)

N260E/60 ~90° from the tunnel drive direction (perpendicular to lineament line)

Conclusion

The performance of TBM, thus the cost scheduling and time of project completion, is greatly affected by the geological conditions and discontinuity properties of rock mass. Unexpected high water ingress and poor rock mass conditions may dramatically reduce the average progress rates and practical consequences. An attempt is also made for selecting a proper TBM parameter factor, as Boring Energy has been chosen based on the relationships existing between TBM-1 performance, hydrogeology and rockmass.

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References

1. Burshtein. L. Kh 1969, “The problem of conformal transformations of a circle into non-overlapping regions”, *Mat. Zametki*, vol. 6, no. 4; pp. 417–424
2. Cigla M., Yagiz, S., Ozdemir, L. 2001. Application of tunnel boring machines in underground mining development. In: Unal, E. *et al.* (eds*.), Proc., of International Mining Congress and Exhibition of Turkey, 155-164, Ankara, Turkey.*
3. Karlsrud, K 2002, *Control of water leakage when tunnelling under urban areas in the Oslo region*. Norwegian tunnelling society (NFF), publication 12, pp. 27-33.

4. Kohno, M, Maeda, H, Kage, I, Kotake, J & Nii, M 2010, Method of axial point load strength test for smectite-bearing rocks, *JSCE Journal of Geotechnical and Geoenvironmental Engineering (Doboku Gakkai Ronbunshuu C)*, vol. 66, no 4, pp. 859–868.
5. Nelson, P.P 1993, *TBM performance analysis with reference to rock properties. In: Hudson*, J.A. (Ed.), Comprehensive Rock Engineering, Excavation, support and monitoring, vol. 4. Oxford, Pergamon Press; pp.261–291.
6. Pitfield, P. E. J., Teoh, L. H. & Cobbing, E. J. Textural variation and tin mineralization in granite from the main range province of the Southeast Asian Tin Belt, Volume 25, Issue 3-4, July - December 1990, Pages: 419–429.
7. Shu, Y. K. (1969) Some NW Trending faults in the Kuala Lumpur and other areas. *News. Geol. Society Malaysia*. **17**, 1 -15 pp
8. Stauffer, P. H. (1968) The Kuala Lumpur fault zone: A proposed major strike slip fault across *Malaya. News. Geol*. Society. **15**, 2 – 4 pp
9. Yagiz, S. 2006. TBM performance prediction based on rock properties. In: Cotthem, A. V. *et. al.* (ed), *Proc., multiphysics coupling and long term behaviour in rock mechanics, EUROCK' 06, 663-670. Liege, Belgium.*